THOUSAND-ELEMENT MULTIPLEXED SUPERCONDUCTING BOLOMETER ARRAYS

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ABSTRACT

Large format, two-dimensional arrays of close-packed bolometers will enable submillimeter cameras and spectrometers to obtain images and spectra orders of magnitude faster than present instruments. The South Pole Imaging Fabry-Perot Interferometer (SPIFI) for the AST/RO observatory and the Submillimeter and Far-InfraRed Experiment (SAFIRE) on the SOFIA airborne observatory will employ a large-format, two-dimensional, close-packed bolometer arrays. Both these instruments are imaging Fabry-Perot spectrometers operating at wavelengths between 100µm and 700µm. The array format is 16x32 pixels, using a 32-element multiplexer developed in part for this purpose. The low backgrounds achieved in spectroscopy require very sensitive detectors with noise equivalent powers (NEPs) of order $5\cdot10^{-18}$ W/√Hz. Superconducting detectors can be close-packed using the Pop-Up Detector (PUD) format, and SQUID multiplexers operating at the detector bas temperature can be intimately coupled to them. We are fabricating an engineering model array with this technology which features a very compact, modular approach for large format arrays.

SIZE MATTERS

When it comes to moderate-resolution spectroscopy, bigger is better.

Spectroscopy of galaxies typically requires a velocity resolution of ~100km/s, or $R\equiv\lambda/\Delta\lambda\sim3000$. Let's assume we're working in the far-infrared (FIR), in the 100-500µm range. Detection using heterodyne techniques yields a quantum-limited noise of $0.6\text{-}6.0\cdot10^{-17}$W/√Hz ($T_N$=50-250K). Background-limited NEPs are less than this, so a direct detector will avoid excess noise.

Since energy-resolving detectors don't yet exist in the FIR, we'll have to build an optical spectrograph – preferably a grating or Fabry-Perot for optimum sensitivity. If we want to image large fields in line emission, we'll build an imaging Fabry-Perot; otherwise we'll build a long slit or integral field grating spectrometer. Either way, these instruments call for really big planar bolometer arrays in the focal plane. Tens of spectral or spatial elements on a side is a good scale, implying kilopixel-scale arrays are needed.

Engineering large bolometer arrays.

Engineering a working large bolometer array will be a major challenge in the near future. The state-of-the-art bolometer array is best represented currently by the HAWC engineering prototype, being used in the SHARC-II instrument[1]. This array, completed at NASA/GSFC in early March of 2002, is designed in a 12x32 format with 384 bolometers featuring high-impedance doped silicon thermistors (Figure 1). This design requires 384 warm (~100K) JFET amplifiers and a very complex, mechanically daunting assembly (Figure 2). This effort may well represent the peak of semiconducting bolometer array technology.

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The HAWC/SHARC-II arrays feature a truly groundbreaking innovation in the assembly process: a geometry that enables the detectors to be close-packed (>95% filling factor) with the wiring brought out behind the focal plane surface.

Figure 1. HAWC engineering prototype array for the SHARC II instrument. The array is a 12x32 (384 pixel) format.

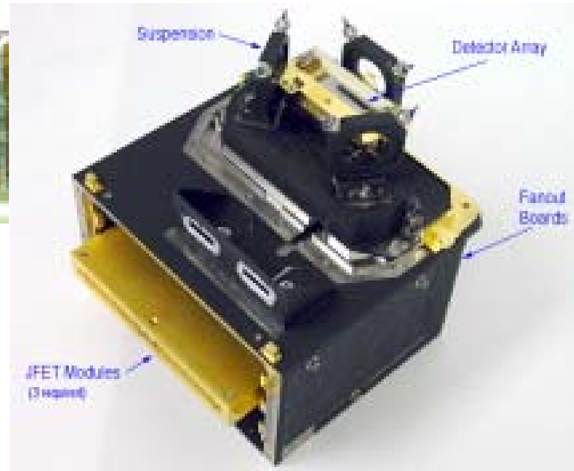


Figure 2. Completed array structure; note the relatively small focal plane area as compared with the overall volume, which is dominated by the warm amplifiers.

Pop-Up Detector (PUD) Architecture.

A very thin Si or SiNx membrane can be folded through large angles without breaking. We manufacture rectangular detector chips that are close-packed linear arrays of 8 or 32 bolometers, as shown in Figure 3. These chips can be folded in half and glued (either to themselves or to a handling structure) as shown in Figure 4. The wiring bond pads are at the lower left edge of the PUD chip.

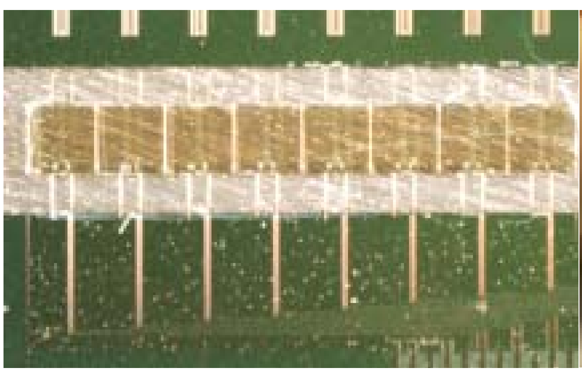


Figure 3. Linear 1x8 bolometer array

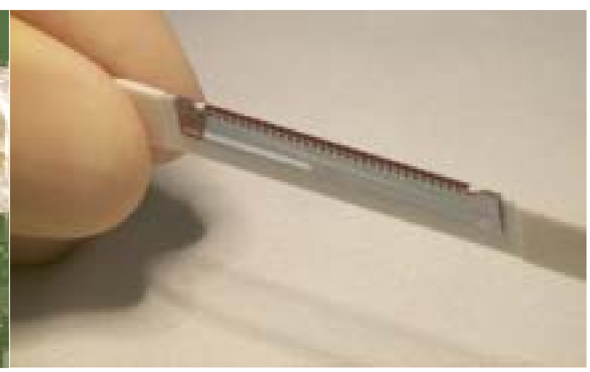


Figure 4. Folded 1x32 array from HAWC.

In order to scale this architecture to thousand-element arrays, we have used the PUD architecture and have tried to simultaneously simplify the engineering (as compared to HAWC/SHARC-II arrays) and to minimize the size and weight of the array assembly. The detectors in this case are multiplexed superconducting transition edge sensor (TES) bolometers. Multiplexed TES bolometers are a new development, but several discussions can be found in the literature[2,3,4].

The arrays described here are intended for use in the SPIFI instrument[5] (G. Stacey, PI) as an engineering model, and in the SAFIRE instrument[6] aboard SOFIA (S.H. Moseley, PI). The individual detector elements are under investigation and are discussed in a companion paper by Jay Chervenak[7]; the cold electronics are discussed by Kent Irwin[8]; the electronics for readout are discussed in a paper by Johannes Staguhn[9]. First results of a systems demonstration have been published using the FIBRE instrument[10,11].

GOING HUGE

A complete array requires consideration of thermal, electrical, and mechanical factors. The array design presented here addresses the complexities of manufacturing a compact, functional detector array. Additionally, ease of assembly is a practical matter that cannot be ignored, and the possibility of repairing array elements at a later date is useful.

Electrical Design:

The circuit diagram for a multiplexed bolometer array using superconducting sensors and SQUID multiplexers[12] is shown at right in Figure 5. The fundamental unit is a 1x32 detector array read out with a single 32-input multiplexer with a 2-stage SQUID amplifier.

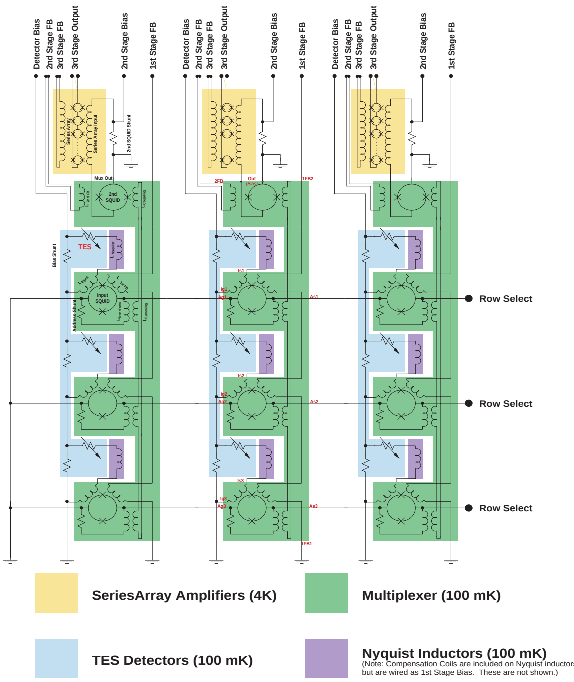


Figure 5. Schematic for a 2-D array of multiplexed TES bolometers with SQUID readout

Detector Array Layout:

A single 1x32 array is fabricated with the TES detector, readout wiring and the detector biasing all manufactured on-chip photolithographically. Alignment holes are included so that the array, once folded, has natural mechanical structures for assembly. This is shown below in Figure 6.

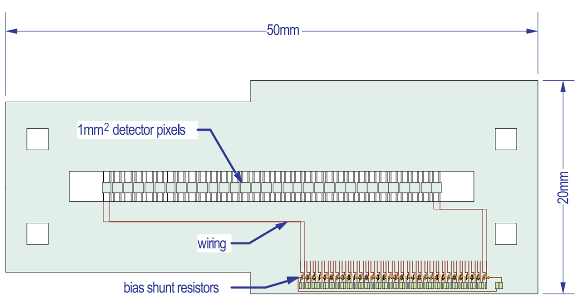
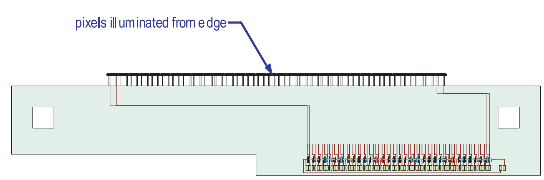


Figure 6. (A) Unfolded 1x32 TES PUD array.



(B) Same array after folding.

Circuit Board:

The circuit board (Figure 7) carries the SQUID multiplexer and a Nyquist filtering inductor, and performs the appropriate fanning out of all leads to connect to warmer stages of electronics. Each board has 32 address lines (signal and return) which are shared among all 1x32 arrays. Additionally, the detector bias and multiplexer feedback and output are included as one pair per board.

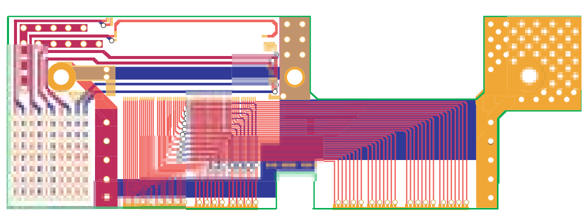


Figure 7. 2-layer circuit board layout

Mechanical Assembly:

After qualifying each 1x32 array, the PUDs are stacked along with their circuit boards. In order to accommodate space for the chips and wirebonds, both elements have cutouts that are staggered. During stacking, left- and right-handed components are engaged in such a way as to avoid collisions. The assembly technique is diagrammed below in Figure 8.

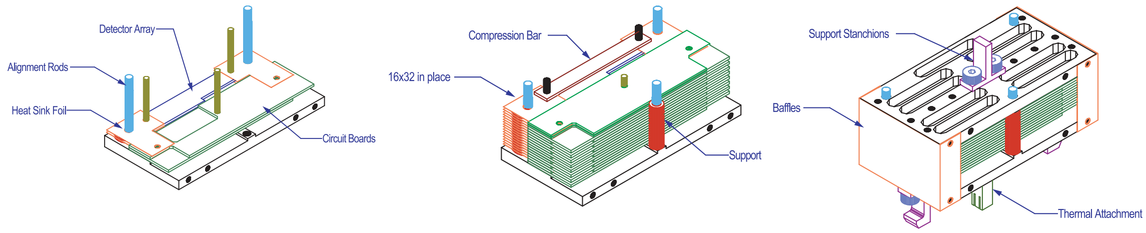


Figure 8. (Left) First two columns stacked with mechanical and thermal components. (Middle) All columns stacked. (Right) Structure closed and baffled, mounting stanchions attached.

Final Assembly:

The array is thermally isolated with a kinematic Kevlar suspension. A mounting structure operated at LHe temperatures supports the array, which is cooled to lower temperatures. The suspended mass weighs ~1/2 lb. Wiring is brought out by superconducting cabling. The focal plane area of 16mmx32mm is >95% filled with detector elements. A filter can be attached over the array. The completed array design is shown in Figure 9, where the connectors for cabling are hidden for clarity.

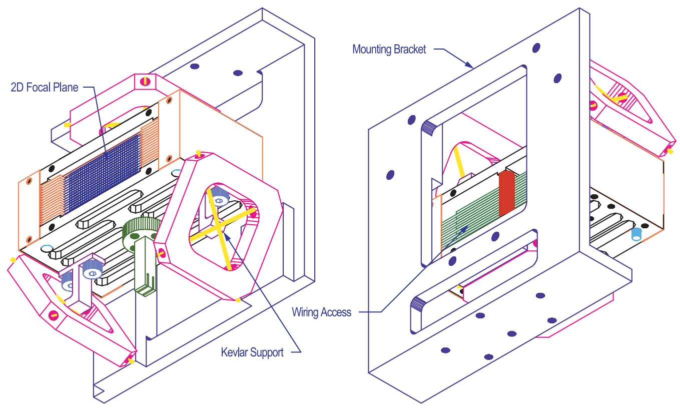


Figure 9. Front and back views of the completed array.

CONCLUSION

We are in the process of assembling an engineering prototype array as a demonstration of an architecture for a kilopixel-scale bolometer array. Pop-Up Detectors are used with superconducting thermistors and SQUID amplifiers to enable a compact array format. The initial detector array will consist of 16x32=512 pixels, but with small changes the same structure can be scaled to 32x32=1024 pixels.

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